Geolocation validation of CERES instruments using radiance measurements

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ABSTRACT

Clouds and the Earth's Radiant Energy System (CERES) instruments are currently flying on two satellite platforms, Terra, launched 18 December 1999 and Aqua, launched 04 May 2002. Both satellites are at a 705-km altitude, in high inclination, polar orbits. Terra crosses the equator at local morning, while Aqua crosses at local afternoon. Each platform carries two CERES instruments. Each CERES instrument contains three scanning radiation-detecting bolometers. The three detectors measure reflected solar and Earth emitted radiation in three bandwidths: shortwave (0.3-5 μm), window (8-12 μm), and total (0.3 to > 100 μm). Earth views of each instrument are geolocated to the Earth fixed coordinate system using satellite attitude, ephemeris, and instrument pointing data.

An analysis has been developed which uses radiation gradients at ocean-land boundaries measured by the CERES instrument as an aid to validate the computed geolocation. The detected coastlines are compared to known map coordinates and an error analysis is performed after a best fit is made in the coastline comparison. Spatial differences are mapped from latitude, longitude to absolute distance in along-track (ground path) and cross-track (perpendicular to ground path) of the satellite. Results of the Terra CERES instruments have shown maximum errors to be within 10% of the nadir footprint size. A description of the coastline detection and error analysis will be presented along with results for the Terra CERES instruments. Initial results from the coastline detection and error analysis for the Aqua instruments will be presented also.

Key Words: CERES, Terra, Aqua, geolocation, pointing accuracy, coastlines

1. INTRODUCTION

Geolocation is the process of computing the latitude and longitude on the Earth's surface associated with a measurement made by a remote instrument. The computation of the geolocation is dependent upon the attitude and ephemeris of the satellite and the instrument's detector pointing vector. The Clouds and the Earth's Radiant Energy System (CERES)[1] instruments' detectors are bolometers that measure radiation in three bandwidths; shortwave (0.3-5 μm), window (8-12 μm), and total (0.3 to > 100 μm). These three detectors are coaligned together and are rotated in two scanning planes, elevation and azimuth, see figure 1. The azimuth can scan up to 6 degrees/sec while the elevation can scan at 63 degrees/sec. The field-of-view of the aperture is 1.3 by 2.6 degrees. This results in a nadir footprint that is optically 16 km in the scanning direction by 32 km wide, but is frequently referred to as an equivalent 20-km circular resolution. For each Earth-viewing CERES measurement, corresponding geodetic latitude and longitude at the Earth's surface and the geocentric latitude and longitude at the top-of-atmosphere (30 km) are computed[2]. This is a complex geometrical computation dependent on high-speed mechanical movements of the CERES instrument's detectors superimposed on the celestial dynamics of a spacecraft in Earth orbit.

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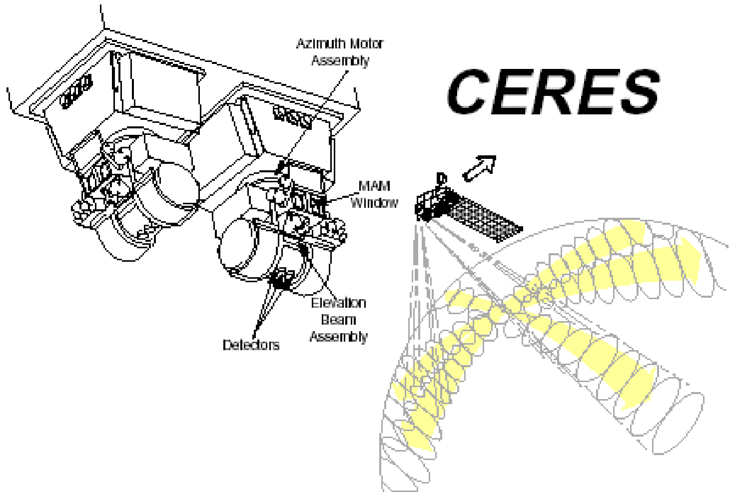

Figure 1: CERES instruments showing rotating azimuth and elevation planes.

An analysis has been developed[3] that attempts to verify the computed geolocation using the radiances measured by these scanning detectors. This analysis involves detecting land-water boundaries (coastlines) using radiance measurements and calculating an error between the corresponding computed geolocation coordinates and known map coordinates. It was first applied to the Earth Radiation Budget Experiment (ERBE) instruments, the precursor to the CERES instruments. Application of this analysis was extended to the CERES proto-flight model instrument flown on the TRMM satellite[4]. The coastline detection and error analysis used during the TRMM flight proved an effective tool in verifying computed geolocation. Until now, this coastline analysis application has been an interactive process where a single scene is analyzed extensively. To use this tool more effectively during the Terra and Aqua missions, this process has been fully automated. This allows months of CERES radiance measurements to be quickly processed and geolocation error trends documented. A description of the coastline detection and error analysis is outlined and the results of the detector pointing error estimates for the Terra and Aqua instruments are presented.

The CERES instruments are currently flying on two satellite platforms, Terra, launched 18 December 1999 and Aqua, launched 04 May 2002. Both satellites are in a 705-km altitude, high inclination polar orbits. Terra crosses the equator in the local morning, while Aqua crosses in the local afternoon. Each platform carries two CERES instruments. Terra carries CERES Flight-Model 1 and 2 (FM1, FM2) and Aqua carries CERES Flight-Model 3 and 4 (FM3, FM4). Additionally, a CERES proto-flight model (PFM) was flown on the TRMM satellite platform.

2. COASTLINE DETECTION ANALYSIS

2.1 Coastline detection concept

As the CERES instrument scans across a land-sea (coastline) interface, a temperature change is sensed resulting in a longwave radiance gradient. During the day, longwave radiances over land are generally higher than those sensed over water. The inverse is true at night. The coastline detection algorithm uses this phenomenon to map out coastlines. The detection algorithm logic decides if the gradient is sharp enough and repetitive enough on successive scans to constitute a coastline. These radiance-detected coastlines are then compared to known map coordinates. An estimate is made of the error in degrees latitude and longitude between the detected coastlines and the map coordinates of the coastlines. The latitude, longitude angle errors are translated to the absolute distance in the along-track (ground path) and cross-track (perpendicular to ground path) of the satellite. The resultant along-track and cross-track estimates can be statistically studied and trended for each CERES instrument.

2.2 Coastline detection algorithm

As the CERES elevation head scans the Earth, the radiances measured from the total channel sensor are used in this algorithm. While scanning, a cubic polynomial is fit to four contiguous footprint measurements. This is a “running cubic polynomial fit" in the sense that upon the next measurement, the oldest measurement is replaced by the newest measurement. Hence, the most recent four measurements are fit with the cubic. By setting the second derivative of the resulting cubic to zero, the location of the inflection point can be determined. This inflection point is considered a detected coastline point when the following conditions are satisfied. First, the inflection occurs between the two inner measurements. Second, the radiance change between the first and fourth measurement is greater than a specified threshold value. Third, the inflection point computed geolocation coordinates are within a specified threshold distance to known coastline coordinates. The public domain CIA World Data Bank II digital map is used for coordinate comparison. If enough coastline points are detected in sequential scans, then the detected coastline points are defined as a potential detected coastline scene.

Before classifying this scene as a true coastline scene, the logic must also distinguish and contrast coastlines from cloud groups. Clouds are known to pose radiance gradients similar to coastline interfaces. A second CERES data product is utilized that contains scene identification and cloud cover information for each CERES footprint measurement. Only clear-sky detected coastlines are retained and analyzed. Coastlines are found and analyzed during daytime and nighttime. The addition of the scene identification allows the analysis to become fully automated and months of CERES radiance measurements may be processed through the coastline detection quickly. Previously the analyst spent many hours interactively searching for a clear scene to process.

3. POINTING VECTOR ERROR ANALYSIS

3.1 Map comparisons

Once a detected coastline is determined, the computed geolocation coordinates are compared to the digital map coordinates and the differences in longitude and latitude are computed. The comparison is made by using an Amoeba Error Analysis[5]. The detected ensemble of coastline crossings are iteratively shifted left and right (latitude) and up and down (longitude) with the average distance errors are recalculated for each iteration. This shifting is accomplished using the downhill simplex minimization algorithm[5] to minimize the rms map crossing distance. Once a successful minimization has been achieved, the resulting latitude, longitude shift is the geolocation error for that detected coastline. The latitude, longitude errors are transformed to cross-track and along-track by using the heading angle (angle off north) of the spacecraft[4]. Numerical experiments were conducted where coastlines taken from the digital map database were processed through the error analysis. The error analysis resulted in numerically zero error corrections. The cross-track and along-track error angles are converted to kilometers by using the arc length of 1-degree longitude radius at the Earth's equator.

3.2 Detected scenes

The detection areas used in statistical studies were limited to exclude the Earth's Polar Regions. Only latitudes between + /– 70 degrees were searched for coastline crossings. Currey[4] showed that non-normal scanning into coastlines skews gradients. Experience further showed that non-normal and highly discontinuous coastlines were being detected near the poles. The resulting cross-track and along-track errors were routinely triple those found in the low to mid latitude regions. The threshold value for a change in radiances across the four measurements making up the inflection point calculation is 10 watt m^{-2} sr^{-1} during the day and 2 watt m^{-2} sr^{-1} for nighttime. An inflection point needs to be within 20 km of the digital map, coastline coordinates for this point to be considered a coastline crossing. Twenty consecutive detected coastline crossings, with an allowable gap of up to three scans throughout, were required to retain the group of detected coastline crossings as a detected coastline scene. The detected coastline scene was subsequently analyzed by the error analysis and the resulting geolocation errors in the cross-track and along-track coordinate system were determined.

Figure 2 illustrates a detected scene using radiances measured by the total channel sensor on the Terra FM1 instrument. This occurred on 26 December 2000 during daytime while the spacecraft was descending and passing over the Red Sea. Plotted is the instantaneous filtered radiance with the detected coastline (inflection) points illustrated as black circles. Sections of the digital map that were compared to the detected coastline are plotted also. The resulting geolocation errors were computed as +1.4 km in the cross-track direction and –3.3 km in the along-track direction.

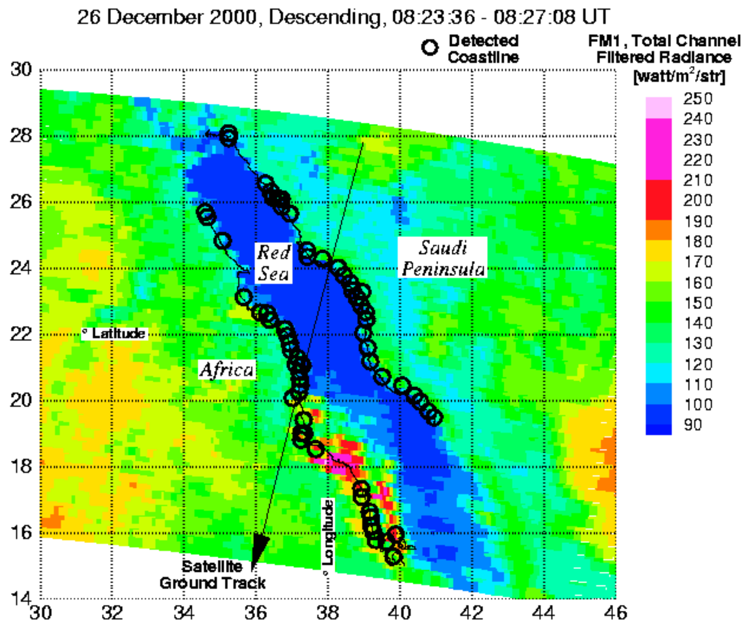

Figure 2: Detected scene with superimposed digital map coordinates and total channel radiances.

4. RESULTS AND DISCUSSION

4.1 Overview

To assess the geolocation accuracy and trends of the Terra and Aqua CERES instruments; the coastline detection process was implemented on selected days throughout the year. Typically, a data day was processed to find individual scenes, monitor these scenes for excessively large errors, and flag scenes in the Polar Regions. Valid scenes are then collected and the resulting cross-track and along-track errors are averaged. To perform this process on a daily basis would result in excessively large volume of scenes.

For purposes of this study, valid scenes were collected for the same three days in a given month. Statistics were then derived to provide a single averaged cross-track and along-track error for the month. An additional metric, Radius, was also computed. The Radius represents the magnitude of the vector sum of the cross-track and along-track errors. This study was further limited to data collected every three months, with a cumulative average of all datum points is computed to identify the current errors to date. Based on this study, for both Terra and Aqua the CERES instruments are providing consistent error metrics over time with no significant change in the magnitude of the geolocation errors as determined via the coastline detection analysis.

4.2 Terra

The quarterly geolocation errors for the CERES instruments on the Terra satellite are plotted in figure 3. These errors are plotted on a cross-track, along-track grid. For the FM1 instrument, all of the monthly averaged points in the cross-track direction indicate essentially no bias. The cumulative cross-track averaged value is approximately zero. However, in the along-track direction, all of the monthly averaged points show an apparent negative bias to the direction of flight. The cumulative averaged value is approximately 1 km aft. For the FM2 instrument, there is an apparent bias away from the direction of the scan in the cross-track direction. The cumulative averaged error is about 1.5 km behind the scanning direction. In the along-track direction, all of the monthly averaged points also show a negative bias to the direction of flight. The cumulative averaged value is 0.5 km aft.

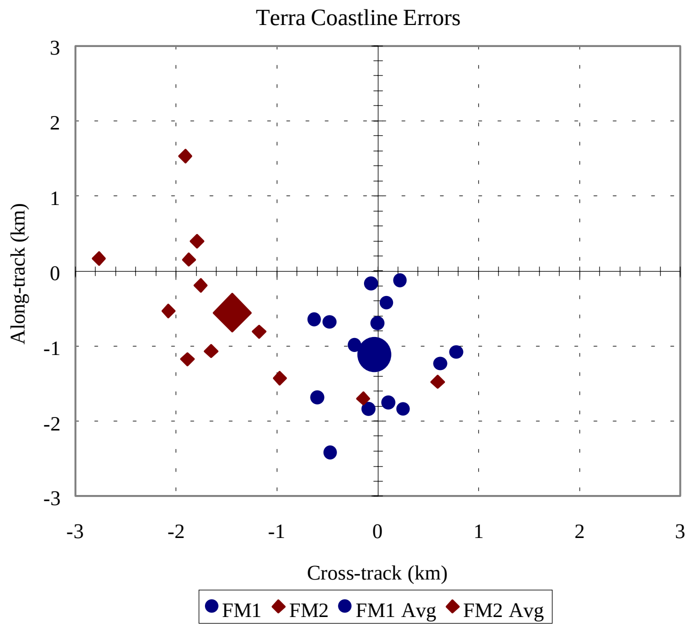

Figure 3: Terra coastline errors.

4.3 Aqua

As the CERES instruments on Aqua have been in orbit for a little over one year, there are less error values on the analogous plot seen in figure 4. For the FM3 instrument, there is an apparent bias in to the cross-track scan direction. The cumulative averaged error is approximately 1.4 km ahead of the scanning direction. In the along-track direction, all of the monthly averaged points show an apparent negative bias to the direction of flight. The cumulative averaged value is approximately 0.8 km aft. For the FM4 instrument, there is an apparent bias away from the cross-track scan direction. The cumulative averaged error is about 0.5 km behind the scanning direction. In the along-track direction, all of the monthly averaged points show essentially no bias error to the direction of flight.

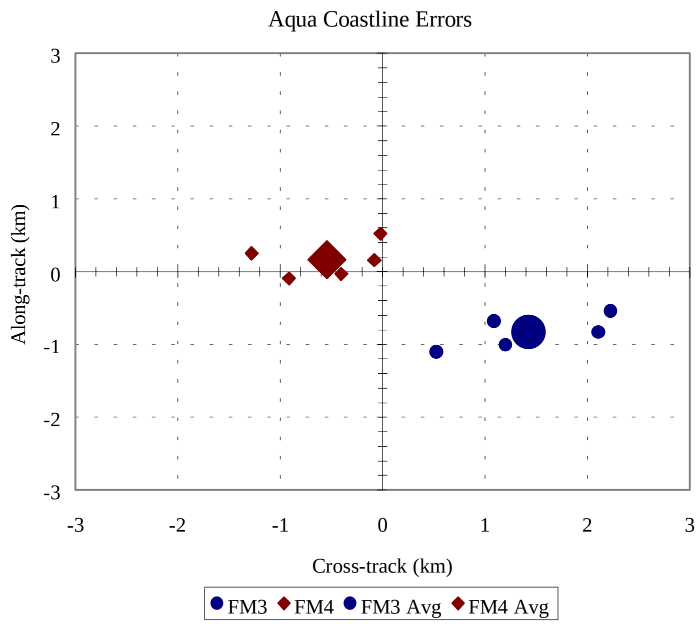

Figure 4: Aqua coastline errors.

4.4 Trending
Figures 5 and 6 show time series trending results for the Terra and Aqua CERES instruments for these selected months. The cross-track and along-track errors do not appear to be significantly changing with time. The additional metric, Radius, is also shown. These values also do not appear to be significantly changing with time.

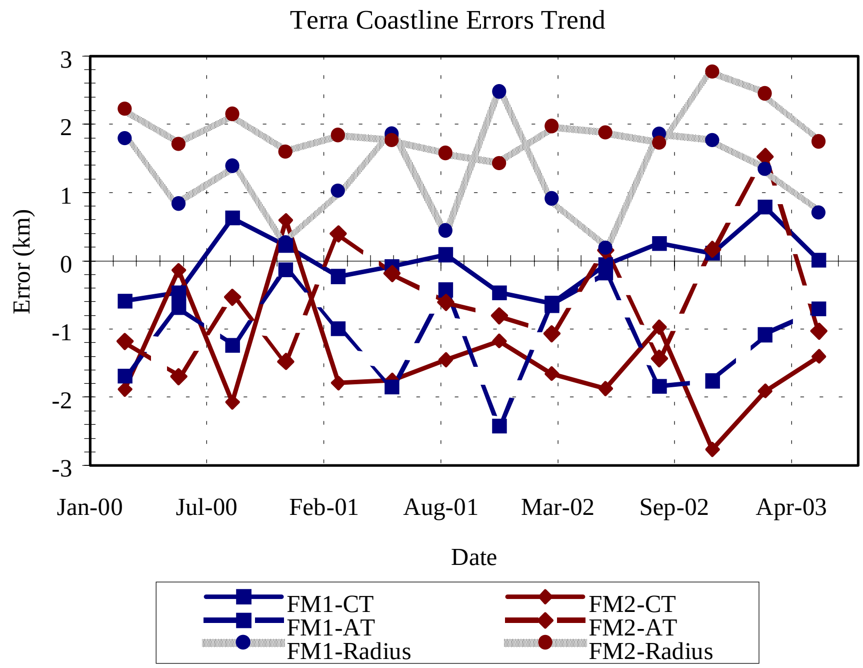

Figure 5: Terra coastline trending errors.

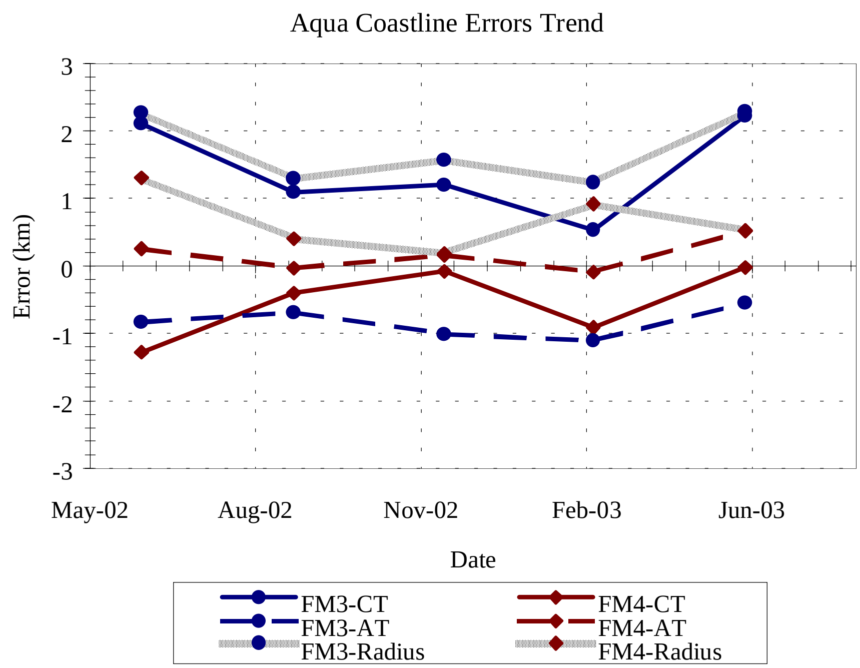

Figure 6: Aqua coastline trending errors

5. CONCLUSIONS

An automated process to assess geolocation with measured radiance has been developed for the CERES instruments. The procedure was described and applied to the CERES instruments on the Terra and Aqua satellites. Results show that the geolocation errors are well within the 20-km nadir footprint size of the CERES instruments. Trending results show little variation over time for all four CERES instruments studied. The CERES instruments will continue to be monitored.

ACKOWLEDGMENTS

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REFERENCES

1. B. A. Wielicki, B. R. Barkstrom, E. F. Harrison, R. B. Lee III, G. L. Smith, and J. E. Cooper, "Clouds and the Earth's Radiant Energy System (CERES): An Earth Observing Experiment", *Bulletin of American Meteorological Society*, **77**, pp. 853-868, 1996.
2. "Release B SCF ToolKit User's Guide for the ECS Project", June 1998.
3. L. H. Hoffmann, W. L. Weaver, J. F. Kibler, "Calculation and Accuracy of ERBE Scanner Measurement Locations", *NASA Technical Paper 2670*, 1987.
4. J. C. Currey, G. L. Smith, R. W. Neely, "Evaluation of Clouds and the Earth's Radiant Energy System (CERES) scanner pointing accuracy using a coastline detection system", SPIE Conference of Earth Observing Systems III, San Diego, CA, SPIE Vol. 3439, July 1998.
5. W. Press, B. Flannery, S. Teukolsky, and W. Vetterling, "Numerical Recipes in C", pp. 305-309, Cambridge University Press, Cambridge, 1988.